US Geological Survey, Alaska Science Center
Polar Bear Research Program

Strategic Science Plan

Establishing Causation and Projecting the Effects of Environmental and Anthropogenic Stressors on Polar Bear Populations

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Introduction

The USGS Alaska Science Center leads long-term research on the polar bear (*Ursus maritimus*) for the U.S. Department of the Interior. For many years, the primary focus of this program has been on the population dynamics and habitat ecology of the southern Beaufort Sea population, and the findings from those studies have been critical to understanding polar bear ecology and population trajectories. This substantial body of work has demonstrated that the fate of polar bears is inexorably linked to the health of the Arctic ecosystem, particularly the availability of sea-ice habitat (e.g., Amstrup et al. 2008, 2010; Durner et al. 2009). Unfortunately, the Arctic ecosystem is undergoing unprecedented environmental change. In the summer of 2012, satellite-derived sea ice extent reached a record low 3.41m km^2, which represents a dramatic 18% decline in extent from the previous record low set in 2007. The physical environment of the Arctic is changing more rapidly than predicted and these changes, by and large, are not gradual— they exhibit classical "tipping point" characteristics in that they result in rapid and extensive state changes (Solomon et al. 2009). For long-lived species such as the polar bear, the rapidly changing physical environment creates a temporal mismatch between cause and effect: the effects of rapid environmental change may not be immediately manifested at the population level. Because of the potential for a cause and effect lag, there is a need for research that provides finer temporal resolution of the response of polar bears to their rapidly changing environment. The research outlined in this strategic plan has been developed to allow for near real-time assessments of population response to ecosystem stressors long-term population projections.

Climatic warming is predicted to be the most influential factor driving the change in the timing of sea-ice formation, break-up, and annual extent in the Arctic (ACIA 2005). Since the 1980's, Arctic warming has accelerated, resulting in subsequent decadal declines of annual mean and summer minimum ice extents of 2.7% and 7.4%, respectively (IPCC 2007). These declines are ominous for polar bears (*Ursus maritimus*), an ice-obligate apex predator that relies on sea ice as a platform for hunting prey (primarily ringed seals [*Phoca hispida*]), for mating, migration and, to some extent, denning. The most suitable polar bear habitat occurs over the shallow continental shelf (Durner et al. 2009), where biological productivity is greatest. Continental shelf sea-ice habitat is particularly vulnerable to climate-mediated loss via earlier break-up and fragmentation due to increased anthropogenic activities (Nelleman 2001, NRC 2003). The relatively narrow niche-breadth of polar bears, along with the projected rapid changes to the Arctic sea-ice ecosystem (e.g., Johannessen et al. 2004), puts the long-term persistence of polar bears at risk (Stirling and Derocher 1993, Hunter et al. 2010).

Despite the general consensus that polar bears are adversely affected by climatic warming, there is a great deal of uncertainty concerning short- and mid-term regional responses (e.g., DeWeaver 2007, Amstrup et al. 2008). In part, this is due to lack of data on 7 of the 19 management units – or subpopulations, such that basic vital rates for those units are inestimable. Further, it has been predicted (Stirling and Derocher 1993; Derocher et al. 2004) and demonstrated (Peacock et al. In Press) that polar bears will initially differentially respond to climate change due to variation and the complex natures between polar bear ecosystems.

Findings from recent USGS research reinforce the consensus on the adverse effects of climatic warming on polar bear populations, but also suggest that physical and biological differences between populations may dampen the amplitude of those effects. For example, new research on seasonal resource selection in the southern Beaufort indicates that extensive and prolonged ice-melt during summer is shortening ice-maximum seasons and displacing polar bears from preferred continental shelf habitats, especially in later years. Meanwhile, a comparison of nutrition and reproduction between bears in the Chukchi and southern Beaufort seas, has found that twice as many bears are fasting in spring in the southern Beaufort, but body size, condition, and reproduction in the Chukchi have not declined despite a 44-day increase in the number of ice-free days. Although the increased number of ice-free days appeared to affect condition in both populations, higher biological productivity and stable or increasing prey populations in the Chukchi Sea likely explain the maintenance of condition. These studies suggest that the rapidly changing physical sea-ice environment has the potential to fragment polar bear habitat in ways that induce declines in body condition but, similar to terrestrial environments, those declines may be modulated by the juxtaposition of sea-ice habitat and prey patches.

Differential responses of polar bears to changes in their sea-ice environment are also being observed within populations. Ongoing research on the onshore ecology of bears suggests the potential emergence of an adaptive event mediated by polar bear behavioral heterogeneities. Concomitantly, or perhaps consequently, as the number of ice-free days increase greater proportions of the southern Beaufort population are choosing to spend time on land during summer rather than embrace uncertainty and follow the retreating sea ice into the Polar Basin. The decision to move on land, and exploit temporally predictable resources such as butchered bowhead whale remains, may represent the emergence of an alternate behavioral syndrome (Sih et al. 2004) within southern Beaufort Sea polar bears that could potentially facilitate adaptation to ice-free summers and buy time to recover their rapidly declining sea-ice habitat. But, the operative word here is “may”: concurrent with the increased occurrence on land is a 33% decline in population abundance (USGS, unpublished data). As a result, it now appears that understanding the relative costs and benefits, and especially the energetic consequences and implications for survival, of staying on retreating ice or moving on shore will be fundamental to projecting the trajectories of populations.

Ultimately, the fate of polar bears will be determined by the fate of Arctic sea-ice ecosystems. Localized adaptations may slow population declines and, in a best-case scenario, result in a remnant, vastly reduced “refuge” population. But the prospect of recovering a single remnant population to its former range is daunting if not unavailing, given the potential consequences of allee effects, inbreeding depression, and bottlenecks, among others (e.g., Amos et al. 2008). The challenges to conservation are substantial and will require creative research approaches to inform strategies for overcoming those challenges. Clearly, what is needed to guide polar bear conservation planning is a circumpolar-based research approach that leverages the efforts of regional research groups and traditional knowledge experts into range-wide inference regarding future trends and trajectories. The findings from our most recent circumpolar genetic analysis (mentioned above) indicate that conducting research and management at multiple spatial scales is both biologically meaningful and necessary— in short, we should not allow preconceived boundaries to constrain the scope of investigations. Indeed, a more prescient approach may be to identify geographical units of genetic mixing and isolation, and divergent life histories, and structure a research program to conduct comparative analyses (i.e., between genetic-life history units) geared towards understanding how these geographic units may respond to short-, mid- and long-term environmental and anthropogenic stressors. That, ultimately, is the goal of this document— to begin developing a collaborative research program that improves our understanding of what it will take for polar bears to persist in the short-term and thrive in the long-term.

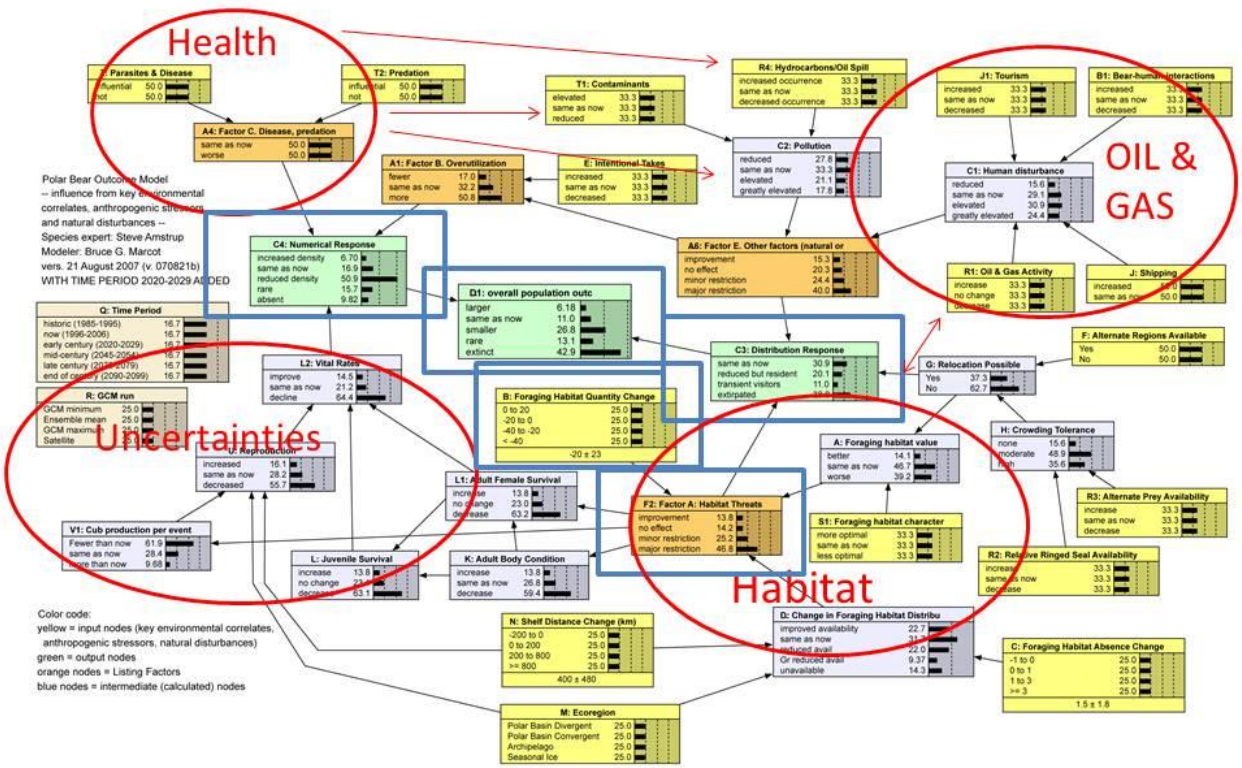
Long-term conservation will depend on informed and careful planning and zoning of the circumpolar Arctic to include areas for human use (e.g., resource extraction, subsistence hunting), core habitat (i.e., refugia) and linkages, and buffer zones. It also will depend on enlisting the support and cooperation of local people by providing opportunities for political empowerment (i.e., co-management), integrating traditional knowledge into research activities, and adapting research methods that, when possible, are consistent with cultural values. This is a tall order for researchers, managers, and policy-makers that will require collaboration between nations, research groups, and cultures. To that end, the timeframe for accomplishing such an objective is beyond the span of this 5-year planning document. Nevertheless, we believe the research we propose below represents a good start down that road.

In this plan, we first introduce our general approach, which includes 4 themes of research. We then describe each of these themes in more detail, including a prospective list of projects that fit within each theme. Finally, we present an implementation strategy that can be used to guide development of annual work plans FY2013-FY2015, study plans targeting the highest priority work, and proposal opportunities that match our goals.

Approach

This strategic plan has been largely informed by the Bayesian network model (Figure 1; hereafter, the BNM) created by Amstrup et al. (2008), and used to inform the U.S. Fish and Wildlife Service's decision to list polar bears as threatened under the Endangered Species Act. The BNM combined general circulation model (GCM) projections of future sea ice with empirical data and expert opinion on the short-, mid-, and long-term responses of polar bears to stressors. The resulting first-generation model projected the extirpation of polar bears from the seasonal ice and polar basin divergent ecoregions by mid-century. This finding, coupled with the observation that sea ice is declining faster than forecasted by GCM projections (Stroeve et al. 2012) is cause for concern. However, there are limitations to the first generation model (see Amstrup et al. 2008 for details), and it is important to note that the BNM was created with the idea that the model would be updated as additional information regarding the responses of bears to stressors became available. With that in mind, we used the first generation model as a template for guiding research activities over the next 5 years (FY 2013-17). Specifically, we used the model to identify nodes that were data deficient (Figure 1) and target those nodes for research (Appendix I).

Figure 1. Bayesian network model of Amstrup et al. (2008) used for planning the research outlined in this plan. Model nodes that were identified as data deficient have been targeted for research and grouped into 3 focal areas (Health, Uncertainties, and Habitat [which includes nodes from "Oil and Gas"]). Data from the 4th focal area (Adaptation) will applied to the multiple nodes.



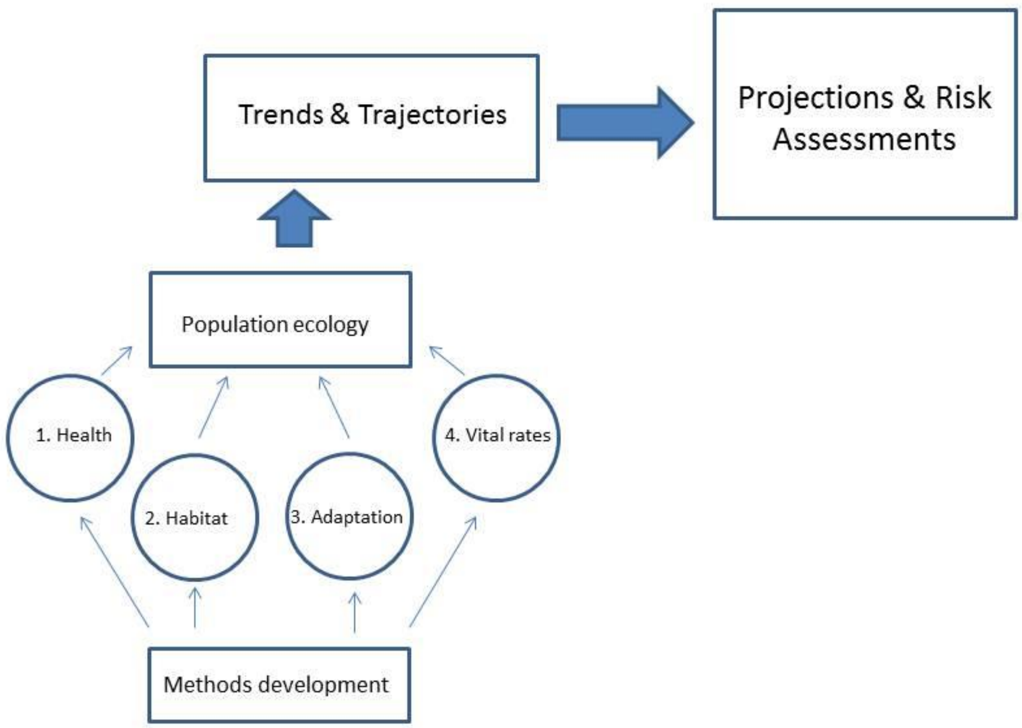
The Polar Bear Project has an extensive long-term database on the population ecology of bears in the southern Beaufort Sea (SB). While this database has value beyond the SB (Vongraven et al. In Press), it has become clear that there is a need to extend our scope of inference to a much larger geographical area if the goal of long-term conservation is to be realized. This will necessitate somewhat of a philosophical shift in how the Polar Bear Research Program conducts research. As part of that shift, we will begin expanding the focus of our population ecology work from assessing annual dynamics in the SB to projecting ecoregion trends and trajectories. Moreover, because our recent comparative studies have been particularly fruitful for elucidating possible mechanisms of polar bear responses to a changing environment, we will prioritize collaborative research that leverages data collected form the southern Beaufort and Chukchi seas with other populations.

Our new strategic approach includes 4 focal areas of research (Figure 2):

1. Effects of a changing Arctic on polar bear health;
2. Reducing uncertainties in population projections and improving methodological approaches (i.e., “Vital rates”; Figure 2);
3. Development of behavioral-state spatial ecology models; and
4. Assessing the capacity for adaptation and resilience.

By its nature, this philosophical shift will emphasize comparisons between areas (to the extent possible) that are genetically or demographically differentiated or have divergent life histories. We feel this is the most effective approach to reducing uncertainties in subsequent generations of the Polar Bear BN.

Figure 2. Conceptual diagram of the four focal areas of research for FY 2013-17, and how these areas inform our understanding of polar bear population trends and trajectories.



Effects of a Changing Arctic on Polar Bear Health

Hypothesis: Climate change will cause direct and indirect effects on polar bear health. Direct effects on health will be associated with increased exposure to disease-causing agents, changes in the rate of contaminant exposure, and changes in the availability and/or quality of food resources. Indirect effects will be associated with increased exposure to resource extraction activities, changes to the distribution of bears, and increased environmental heterogeneity.

Goal: Climate change has the potential to drive profound changes in the health of Arctic fauna including polar bears. The work listed below will collect data on a variety of systems that help determine polar bear health and use those data to develop a monitoring and surveillance program for detecting change in health over time. Additionally, this work will allow us to develop an understanding of how polar bear populations will respond to a variety of stressors modulated by climate change, including increased contaminant exposure, changes in food web structure, and changes in spatial distribution. Work will proceed along four interrelated lines of inquiry: disease, contaminants, nutrition and energetics, and physiological stress (Figure 3). Information from this work will fill critical knowledge gaps in the Bayesian Network model.

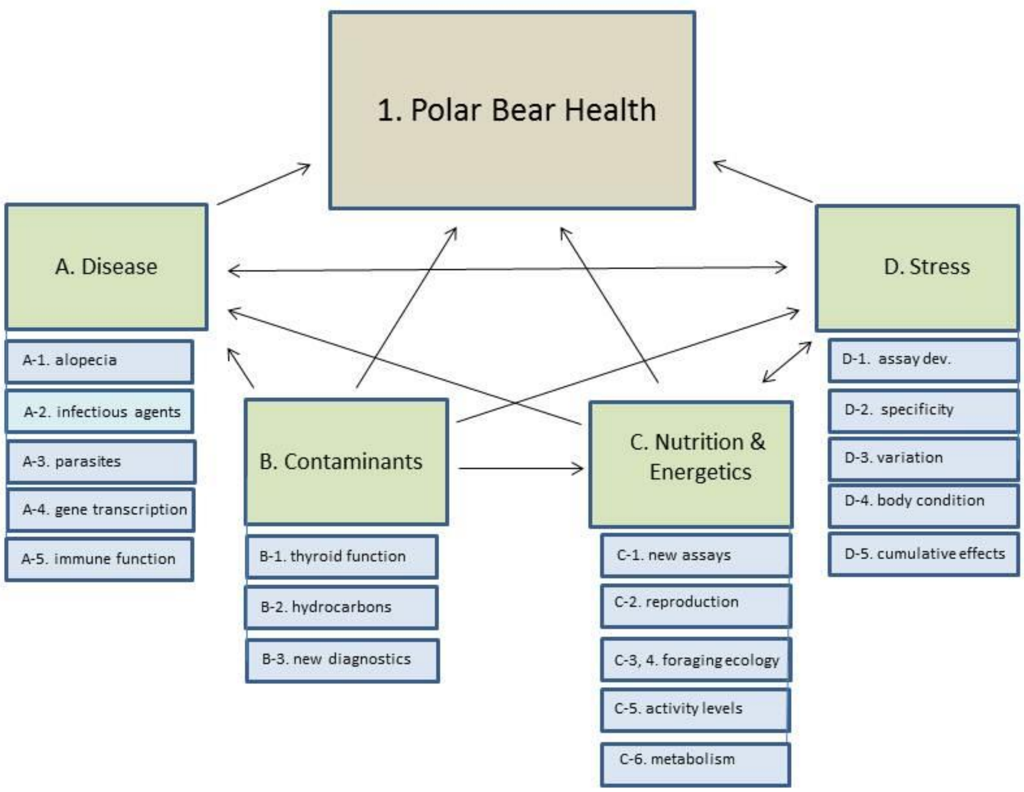
Background: Health is a difficult concept to articulate and measure, but it's critically important to understand: an animal's health reflects the interaction between its behavioral choices and the environment. Because of this, measuring changes in health over time has great potential for revealing important associations between environmental stressors and population dynamics. Unfortunately, the nexus between ecological processes and animal health is poorly understood. In part, this is because most ecologists generally collect observations at an organizational scale— i.e., the individual— where manifestations of health (i.e., signs and symptoms of disease) are generally too complex and far removed from the causative events (Moore et al. 2006). This approach limits the utility of using health assessments for detecting and predicting consequences of environmental stress.

The health of an individual is best assessed at lower levels of biological organization, such as molecular and cellular levels, where it is more feasible to develop a mechanistic understanding of how different environmental stressors may modulate organismal function and expression (Livingstone et al. 2000). Processes that occur at organismal levels can have cascading effects on the distribution, abundance, and fitness of individuals at local, regional, and global scales (Somero 2005). Hence, "distress signals" at lower levels of organization should be capable of functioning as sentinel biomarkers indicative of adverse responses to larger-scale perturbations such as ecosystem stressors. However making the causal link between distress signals and stressors will require a mechanistic understanding of how large-scale environmental stressors are translated into organismal (e.g., hormone production, immune response) and cellular signals (e.g., protein production, gene expression). For polar bears, predicting the effects of climate change on populations will necessitate understanding how bears filter signals via both behavioral (e.g., movement, habitat selection, foraging patterns) and physiological responses (e.g., nutritional restriction, acute or chronic stress, immune function).

There is information available on some factors that contribute to polar bear health, namely exposure to contaminants and infectious disease agents. However, this work is primarily phenomenological— for example, it reports disease prevalence, summarizes titer levels, or reports concentrations of contaminants detected (e.g., Rah et al. 2005, Bentzen et al. 2008, Kirk et al. 2010). What is most needed is the identification of causative links between factors that determine health and population-level processes. The Polar Bear Project will seek to identify those links by developing a line of inquiry focused on physiological ecology. Research within this focal area will emphasize the development and application of biomarker-based assays to better understand the link between environmental change and bear health.

The steps in elucidating the link between ecological processes and polar bear health involve (i) identifying physiological processes believed to be most sensitive to environmental change, (ii) identifying biomarkers for those physiological processes, (iii) measuring those markers and referencing those measurements to a range of values that reflect "normal" physiological functioning, and (iv) identifying a link between environmental and physiological heterogeneity. This work will provide integrated, long-term data on polar bear health within a framework that will allow incorporation into the Bayesian network model. Additionally, it will provide the necessary data products to develop a modeling framework for evaluating cumulative and/or synergistic effects of multiple stressors on population vital rates.

Figure 3. Lines of inquiry (disease, contaminants, nutrition and energetics, and stress) and inter-relationships for the polar bear health focal area.



Disease

Climate warming has been associated with a global increase in disease in marine organisms (Kuiken et al. 2006). Some of these increases involve changes in the bioclimatic envelope of pathogens (Cook et al. 1998), range expansion by vectors (Lindgren et al. 2000), and decreased immune function in hosts (Landgraf et al. 2005)— all of which are hypothesized to be modulated to varying extents by climate change. Unfortunately, these types of data are rarely integrated with demographic data to determine whether effects of diseases are significant at the population level. The Polar Bear Project has a wealth of demographic data that can be applied to filling this information gap and used to determine whether disease may be a limiting factor for Alaska's polar bears.

Objectives:

1. **Alopecia**. Determine the causative agent of recurrent alopecia and the implications for polar bear health, including effects on thermoregulation.
2. **Serological survey**. Serological survey of ursids for *Brucella* spp. (e.g., Garner et al. 1997), *Coxiella burnetii*, and other emerging zoonoses.
3. **Viral survey**. Use high throughput genetic sequencing to identify all viruses (including endogenous/non-pathogenic) present in polar bears from a circumpolar sample. Directly transmitted parasites can be used to gather information on the temporal and spatial characteristics of host species. For example, fast-evolving viruses have been used to reveal contemporary population structure in host species that were not observable using host genetic data (e.g., Biek et al. 2006). If such fast-evolving viruses (e.g., lentiviruses) are present in polar bears, they may prove useful in revealing near real-time changes to circumpolar population structure in response to habitat change. This work may be used to inform methods used to study polar bear adaptation and resilience.
4. **Gene expression panel**. Develop a gene transcript panel for polar bears that can describe physiologic changes and thus identify potential environmental stressors to individuals and within populations. This is foundational work for future assessments of the potential for using gene transcription as a tool to measure effects of a changing Arctic on polar bears. This work may also include the development of blood leukocyte transcript profiles for polar bears to be used in evaluating bear health. Leukocyte genes function within multiple physiological systems, including those that regulate immune-modulation, inflammation, cell protection, tumor suppression, and cellular stress response. Evidence from sea otters suggests these genes can be modified by a variety of stressors. If this is true for bears, the genes may be effective biomarkers for measuring the effects of a variety of ecosystem stressors on bear health.
5. **Assessment of immune function**. Assessment of genes associated with adaptive immune response in polar bears. This work will assess genetic variation and expression at genes associated with innate and adaptive immune response in polar bears.

Contaminants

Anthropogenic contaminants, like organochlorines and heavy metals, are transported to the Arctic via long-range atmospheric transport and ocean currents (e.g., de Wit et al. 2004). These contaminants become a concern for polar bears because Arctic food webs, which are characterized by high lipid levels in biota, concentrate lipophilic contaminants in upper trophic levels (Fisk et al. 2003). Additionally, bears go through an annual cycle of rapid fat accumulation that potentially raises the breadth and potency of contaminant exposure. Although there is substantial research documenting the occurrence and concentrations of contaminants in polar bears, there is a dearth of information on how contaminants influence population dynamics. Thus, rather than solely measure contaminant exposure, we will also study the biological effects through the development of contaminant-sensitive biomarkers.

Objectives:

1. **Endocrine disruption**. Evaluate the relationship between contaminants and thyroid function and vitamin A concentrations. Endocrine-disrupting contaminants can affect circulating levels of thyroid hormone (predominantly thyroxine [T4]) and vitamin A, which are important to growth and development (Morse 1995).
2. **Baseline exposure to hydrocarbons**. Characterize baseline exposure to hydrocarbons associated with resource extraction practices. Baseline information may be important for assessing the effects of increased resource extraction on bears.
3. **Gene expression and contaminants**. The pathophysiologic effect of contaminant exposure can impact multiple organ systems and physiological pathways (Bowen et al. 2007). Gene-based health diagnostics have proven useful for assessing the health of some marine mammals (e.g., sea otters; Bowen et al. 2011), but no such tools exist for polar bears. Work for this objective will include:
   - (i) Developing real-time polymerase chain reaction (qPCR) assays to measure differential transcript levels of multiple genes responsible for mediation of detoxification and immune function in polar bears.
   - (ii) Establishing a reference range for those genes of interest across multiple management boundaries.
   - (iii) Determining if a relationship exists between contaminant exposure and immune system function.

Nutrition and Energetics

One of the primary mechanisms by which reduced sea ice appears to be affecting polar bear populations is via reduced body condition and associated effects on reproduction and cub survival. This is hypothesized to be largely attributed to declines in foraging opportunities resulting from a decline in the duration of sea ice cover over productive habitats where ice seals, the primary prey of polar bears, occur. One way in which polar bears might cope with reduced foraging opportunities, particularly during the annual sea ice minimum, would be to reduce energy expenditure through reduced activity. This may occur primarily during the annual sea ice minimum when the net cost of continued searching for prey could exceed the cost of foregoing foraging opportunities by resting until prey become more accessible. Alternatively, polar bears might increase activity levels in order to reach key resting or denning habitats on land or to find more dispersed food resources over a fragmented sea ice landscape. Understanding the nutritional and energetic mechanisms by which body condition and reproduction are affected by sea ice loss will aid in refining projections for the future status of polar bear populations as sea ice habitat continues to decline.

Objectives:

1. **Biochemical metric of body condition**. Develop and validate a biochemical assay that can be used to quantitatively assess physical condition. This work is in progress and will focus on the development of adipose lipid content as a quantitative metric of polar bear body condition.
2. **Consequences of a lengthened ice-free season**. Determine whether there are the nutritional and/or reproductive consequences of a lengthened ice-free season in the Chukchi Sea. This work will use 4 years of recent polar bear location data in the CS, to (i) determine the length of time denning and non-denning bears spend on Wrangel & Herald islands; (ii) determine relationships between duration of time on land and annual sea ice conditions; (iii) project changes in length of time bears use Wrangel relative to changes in ice distribution; and (iv) model nutritional and reproductive consequences of an increased ice free season.
3. **Variation in feeding ecology**. Determine if temporal and spatial variation in the feeding ecology of polar bears in the CS & SB explains differences in their response to recent sea ice loss. This work will address several questions, including:
    - (i) Have bowhead whales (presumably from subsistence harvested carcasses) and walrus become a larger portion of the diets of bears in the SB & CS in recent years?
    - (ii) How have diets changed with recent sea ice changes?
    - (iii) Is diet related to annual sea ice conditions over the long-term?
    - (iv) Do annual diets of bears in the SB and CS differ – and if so, might this explain differences observed in body size between populations (i.e., can we relate individual diets to body condition)?
    - (v) Are patterns of fasting behavior related to sea ice conditions?
    - (vi) Are relationships between body size and diet similar for the two populations?
4. **Body condition and foraging**. Determine the relationship between individual body condition and foraging ecology (e.g. diet and fasting behavior) and habitat use, reproduction, and survival.
5. **Effects of sea ice loss on energetics**. Determine the potential impacts of sea ice loss on energetic expenditure. This objective will have 3 components:
    - (i) Determine if polar bear activity levels and behaviors (i.e., foraging, swimming, resting) vary with sea ice conditions.

(ii) Determine whether activity levels and behaviors are lower or higher for bears that spend the ice-minimum season on land versus on ice.

(iii) Determine whether seasonal patterns of activity have changed over time with changing ice conditions and whether they differ between BS and CS bears such that differences in energetic expenditure might explain differences in body condition.

6. **Metabolic rates**. Determine field metabolic rates for polar bears and how they may change due to climate warming. This objective encompasses Anthony Pagano's doctoral research and will be integrated with objective 1 to the extent possible. This work will include the following components:

(i) Determine metabolic rates of captive adult female bears while resting, walking, running, and swimming.

(ii) Develop methodology for using accelerometers to quantify free-ranging polar bear behavior.

(iii) Estimate field metabolic rates of adult female bears using accelerometers and GPS location data.

(iv) Evaluate the use of doubly-labeled water to quantify field metabolic rates of adult female bears.

(v) Determine how habitat use and movement strategies may affect energy budgets of adult female bears.

(vi) Project future changes in energetic requirements of adult female polar bears based on general circulation model projections of sea ice extent and distribution.

7. **Methods in foraging ecology**. Identify the most accurate and effective means of monitoring long-term trends in the foraging ecology of polar bears. Currently, two biochemical methods are used to estimate the diet of polar bears: fatty acids in fat biopsies and stable isotopes in blood. Both of these methods require a number of assumptions, some of which have not been tested. There is a need to further investigate the assumptions underlying the application of these techniques and to identify the most accurate means of estimating diets in future studies and from available archived samples to determine long-term trends in diet. Diet shifts may be a way in which bears could experience consequences from sea ice loss or, alternatively, adapt to changing habitat conditions.

(i) Test the assumptions of fatty acid techniques for quantifying diets

a. What is the turnover rate of fat in polar bears?

b. What are the calibration coefficients of fatty acids specific to ursids (rather than the mink values which are currently applied).

(ii) Determine the factors that affect discrimination of stable isotopes in polar bear tissues.

a. What timeframe do samples of serum, plasma, red blood cells, fat, and hair represent? What is the turnover rate of these tissues?

b. What components of the diet (i.e., fat or protein) do these tissues represent and what is the best model for estimating the diet of polar bears using stable isotopes?

c. What is the effect of fasting on stable isotopes in polar bear tissues.
d. Can discrimination factors be determined via simulation models of diet data from wild bears?

Physiological Stress

The stress response is an evolved suite of linked physiological, hormonal, and behavioral cascades exhibited by individuals in response to unpredictable or noxious stimuli (Romero 2004). An acute stress response (i.e., short term), such as "fight or flight" behavior resulting from an encounter with a predator, can be adaptive by shunting blood to large muscles and thereby enabling the stressed animal to avoid capture. Conversely, a chronic stress response (i.e., long-term), such as nutritional restriction, can be maladaptive as prolonged overstimulation of the hypothalamo-pituitary-adrenal axis can lead to reproductive and immune system suppression. Because of this, physiological responses to stressors can be important determinants of survival, reproduction, and health which then determine individual fitness and population dynamics (Aronson et al. 2007, Petes et al. 2007, Helmuth 2009).

Technological advancement in the areas of biochemical indicators of stress and gene expression provides an opportunity to measure the stress response of polar bears to changes in their physical environment. Once elucidated, these physiological responses can be coupled with remote sensing applications to determine how spatio-temporal patterns in the environment influence physiological function. Our working hypothesis is that ecosystem level stressors, such as warming temperatures and diminishing sea ice coverage will manifest in polar bears as part of the physiological stress response. The initial stages of the work will focus on identifying a suite of biomarkers and developing sampling and assay methodologies to use in characterizing effects of stress on bears. The latter stages of the work will focus on integrating physiological, behavioral, and environmental data for predictive modeling purposes. Currently, there is a paucity of integrated physio-ecological assessments of polar bear responses to a changing environment. This gap in knowledge needs to be addressed so that we can better project how environmental change influences physiological processes and, ultimately, population dynamics.

Objectives:

1. **Endocrine methodologies**. Develop techniques/assays to validate the accuracy and precision of measurements of hormones and other endocrine biomarkers in various matrices using captive and free-ranging polar bears. Use the assays to evaluate the potential effects of sample collection (e.g. chase time, processing/restraint time) on hormone and biomarker measurements.
2. **Endocrine profiles for various tissues**. Characterize the relationships among hormones and other biomarkers (e.g. immune function, cortisol receptors, heat shock proteins) in different matrices (e.g. hair, blood, saliva, feces, and urine). Determine if there are 'biologically significant' differences in hormone or biomarker levels as measured among different matrices and/or between captive and free-ranging bears.

3. **<u>Life-history variation in endocrine profiles</u>**. Compare the quantitative and temporal relationships of hormones across the different matrices in captive and free-ranging bears (e.g., how is circulating cortisol reflected in measurements made in feces). This work will investigate natural variation in hormones (e.g. cortisol, corticosterone, aldosterone, catecholamines, reproductive hormones, thyroid hormones, etc.) responsible for the stress response in bears as it relates to the life-history (e.g. sex, reproductive state, age) and physiological states (e.g., fasting vs. non-fasting, nursing), and investigate whether these hormones and/or biomarkers have predictable annual or diurnal cycles.
4. **<u>Effects of stress on body condition</u>**. Determine if a relationship exists between stress responses and measures of body condition, reproduction, and resource use (e.g., use of on-shore habitats vs. sea ice, use of bowhead whale bone piles, use of on-shore habitats vs. sea ice).
5. **<u>Modeling cumulative and synergistic effects</u>**. Develop a modeling framework to evaluate cumulative and/or synergistic effects of multiple stressors on population vital rates (e.g., reproductive rate, survival, maternal condition).

Population Ecology: Reducing Uncertainties in Population Projections and Improving Methodological Approaches

Goal: develop and/or adapt sampling and analytical methods for use in estimating polar bear vital rates, population and survival modeling, and modeling of long-term trends and trajectories. Core work in this focal area will involve (i) developing a more rigorous framework to support mechanistic demographic modeling, (ii) evaluate the efficacy of novel sampling and analytical approaches, and (iii) update the Bayesian Network model.

Background: The Polar Bear Project has been collecting data on the population ecology of bears in the southern Beaufort Sea for over 30 years. The dataset is highly valuable— it represents one of the few long-term datasets available for a long-lived sentinel species, and is arguably the most comprehensive time-series data available for polar bears. Yet, despite this, there has been little change in the tools used to analyze these data since the project began. Essentially, methods for modeling polar bear population dynamics have not progressed much beyond the Cormack-Jolly-Seber (Cormack 1964) approach, which conceptually dates back to the Schnabel census (Schnabel 1938, Seber 1986). Given the complexities of processes determining polar bear vital rates and population dynamics, there is a great need to evaluate if the CJS approach— including data collection methods and protocols— is still warranted or whether other approaches may be more rigorous and tractable.

Objectives:
1. **<u>Power analysis</u>**. Conduct a power analyses to determine (i) what level of confidence in estimates of population size and trend is necessary to detect increases or declines at various threshold levels; (ii) optimal sample sizes of bears to capture and biopsy dart for mark-

recapture based analyses; and (iii) levels of confidence required to detect changes in other vital rates, such as body condition and other health profiles.

2. **<u>Southern Beaufort vital rates</u>**. Provide up-to-date population, survival, and recruitment estimates for the Southern Beaufort Sea population.
3. **<u>Onshore ecology</u>**. Continue to estimate the numbers of bears coming on shore in late summer and assess differential survival and fitness for bears that spend time on shore versus remaining on sea ice.
4. **<u>Hierarchical population modeling</u>**. Evaluate the efficacy of using Bayesian Hierarchical Models (BHM) to explore the relationships between environmental measures, stressors, prey, and polar bears. Using a Bayesian approach, similar to that used for the network model, we will develop an ecosystem model that unites environmental conditions, multiple trophic levels, and predator-prey dynamics, and provides information on how model elements relate to one another and that can be used to make predictions from the linked elements of the model. These predictions would reflect ecosystem responses and, just like the network model, areas of uncertainty could be identified and addressed over time to improve the rigor of predictions.
5. **<u>Remote sensing technology</u>**. Evaluate the efficacy of using UAS and remote sensing technology to estimate the abundance of polar bears on shore during summer. This study will determine if UAS and/remotely-sensed imagery maybe effective tools for estimating the abundance of bears, by comparing them to standard abundance estimation methods (aerial survey).
6. **<u>Update the Bayesian Network model</u>**. Update the cumulative effects model (Bayesian Network model) to produce forecasts that reflect new information about stressors to polar bear populations. The forecasts will use updated sea ice projections under "business as usual" and "emissions mitigation" scenarios.
7. **<u>Improving population modeling methods</u>**. Develop an improved modeling framework for evaluating factors driving trends in polar bear abundance and demography. This work will focus on the development of mechanistic models that remedy some of the limitations of approaches based on the Cormack-Jolly-Seber approach, and may include the development of new multi-state models.
8. **<u>Monitoring methods for the Chukchi Sea population</u>**. Identify the best approach for monitoring the long-term status of the CS polar bear population. The CS polar bear subpopulation is a difficult population to study relative to population size and survival rates. Traditional approaches, including physical capture-recapture, are less effective due to broad spatial distribution of individuals over the large expanse of the Chukchi and northern Bering Seas throughout the year and the absence of logistical bases in Chukotka and on Wrangel Island. Alternative approaches will need to be considered, including the potential use of ecological indices in lieu of quantitative estimates of survival and population size or growth rates.
    (i) Can population size and survival rates be estimated via a multi-source (genetic and physical capture) capture-recapture approach?

(ii) Can a population size estimate be obtained via aerial survey?
(iii) Are there ecological indicators, such as reproductive measures, body condition, or harvest data that can be used in lieu of quantitative estimates of population size and survival to more efficiently monitor the status of the population?

Habitat Ecology

Hypothesis: rapid change in polar bear sea-ice habitat will cause fundamental changes to bear spatial ecology. These changes may include an increase in the frequency of occurrence on shore, patterns of hunting behavior and success, and life histories.

Goal: develop a better understanding of how changes in habitat are likely to affect polar bear fitness, behavioral choices, and distribution.

Background: Understanding how animals function in their environment is necessary to predict the consequences of environmental change. Unfortunately, much work on habitat ecology is descriptive in nature, but the mechanisms driving the observed behaviors often remain unknown. To reduce the uncertainty of forecasts on the effects of environmental change on polar bears, it is necessary not just to describe patterns of space use but also to explain why patterns occur. The mechanism that explains an observed phenomenon, for example why polar bear body condition and survival are impacted by sea ice loss, is important for improving forecasts which, in turn, provides valuable information to policy makers for their decisions. Work in this area represents the logical extension of earlier work (e.g., development of resource selection functions, on-shore ecology) and investigates mechanisms of behavioral decisions, life history differences, biogeographic patterns, and potential responses to increased resource extraction activities.

Objectives:

1. **Links between sea ice loss and on-shore fidelity**. Determine if sea ice loss has affected the amount of time bears spend in water vs. on ice and land.
2. **Habitat change and predation**. Characterize long-term patterns of prey selection and changes to the distribution of hunting habitat. Predator-prey interactions are determined, in large part, by how predators and prey respond to heterogeneity in the landscape (Atwood et al. 2009). In the Arctic, the conditions that modulate the distribution and movement of sea ice have been steadily changing, as has polar bear habitat use and body condition. Because of the potential link between habitat change and bear nutritional plane, there is a need to determine how the changing sea-ice landscape may be affecting bear hunting behavior. This work will:
    (i) Characterize patterns of prey selection by bears.
    (ii) Characterize the distribution and fine-scale characteristics of kill sites.
    (iii) Determine whether trends exist in hunting behavior (i.e., prey selection and kill site attributes) over time (e.g., > 20 yr) and how any trends may relate to climate change and changes in bear condition.

3. **<u>Polar bear biogeography</u>**. Develop a paleoclimatological assessment of past and future polar bear distribution. This objective was motivated by feedback from the USGS Climate and Land Use Program, and will model the influence of climate changes on past polar bear biogeography which can then be used as a foundation for modeling future distribution. This objective will have the 3 components:
    (i) Development of quantitative predictions of past bear distribution based on paleoclimatic proxies.
    (ii) Development of testable ecological hypotheses of past distributions.
    (iii) Provide a statistical assessment of range determinants that can be used to compliment projections of future distributions.
4. **<u>On-shore in divergent and seasonal sea-ice ecoregions</u>**. Compare on-shore spatial ecology in divergent and seasonal sea-ice ecoregions. This work will be a collaborative effort with the Greenland Institute of Natural Resources and compare the spatial ecology of bears using on-shore habitats in Baffin Bay and on Alaska's northern coast (southern Beaufort Sea management unit). The Baffin Bay management unit is part of the seasonal ice ecoregion, characterized by an historical ice-free period during summer and early fall, and bears have a long history of using on-shore habitats during the ice-minimum season. The southern Beaufort management unit is part of the divergent ice ecoregion, where annual ice retreats into the polar basin during summer and bears have the choice of following the retreating ice or summering on land. Over the last 7 years, a trend has emerged where more bears are spending a greater amount of time on land during summer. We will compare arrival and departure times relative to sea-ice coverage, on-shore patterns of distribution, and movement behavior to get a better understanding of whether the use of on-shore habitats by southern Beaufort bears may be an effective behavioral strategy for adapting to declining sea ice availability.
5. **<u>Effects of climate change on denning behavior</u>**. Determine whether climate change is affecting denning behavior of polar bears. Specifically, this work will examine whether the length of time bears spend in dens has changed as a result of climate change and if length of denning time is different for ice versus land-based dens. If a difference exists, the next step will be to determine the potential consequences for cub survival.
6. **<u>Effects of resource extraction</u>**. The US Geological Survey Arctic Circumpolar Oil and Gas Assessment estimates that up to 2 billion barrels of oil and up to 80 trillion cubic feet of gas are present on- and off-shore of Alaska's North Slope. As the annual extent of summer sea ice declines, exploration and extraction activities in the Arctic will increase. These activities have the potential to reduce the availability and distribution of suitable habitat, fragment travel corridors, and increase the potential for human-polar bear conflict. To that end, this objective will have the following components:
    (i) Determine the spatial response (e.g., attraction or repulsion) of polar bears to on- and near-shore resource extraction activities.
    (ii) Project the distribution of oil spills relative to on- and near-shore habitats and the effects on the availability of suitable habitat.

(iii) Characterize spatial and anthropogenic factors that contribute to human-polar bear conflict around industrial activity centers.

Assessing the Capacity for Adaptation and Resilience

Hypothesis: The ability of polar bears to persist will depend on whether they are able to adapt or recover from environmental stressors driving rapid change in the Arctic. Environmental change will lead to the invasion of novel pathogens and shifts in the phenology of key resources that will require bears to demonstrate plasticity associated with immune function, fasting ecology, and metabolic processes.

Goal: develop molecular biomarkers that can be used to assess the physiological response of polar bears to acute and chronic environmental stressors.

Background: Arguably, long-term persistence of polar bears depends on their ability to either adapt or demonstrate plasticity to significant environmental stressors. The responses of polar bears to such stressors are the integrated result of both direct and indirect processes that can be manifested as declines in physical condition, reproductive potential and, ultimately, survival. However, the response to stressors is often cumulative and, as a result, outward manifestations may not be detectable within a timescale suitable for mitigating long-term effects (Adams 2005). Moreover, it is exceptionally difficult to establish causal relationships between stressors and effects on bears when relying solely on gross observation. Physicochemical-environmental systems are inherently complex and responses can be modified by a multitude of factors including compensatory mechanisms (Power 1997), temporal and spatial scales (Holdway 1996), and interdependence between events and/or stressors (Bart and Hartman 2000). If the causality and effects of stressors are to be better understood, an integrated molecular-environmental-behavioral approach will be needed.

Work in this focal area will build upon the foundation established by the Changing Arctic Ecosystem's biomarker initiative. To a large extent, this research will rely on advances in genomics to include assessments that rely on next-generation genetic sequencing and transcriptomics.

Objectives:

1. **<u>Using fast-evolving viruses to assess contemporary genetic connectivity of polar bears</u>**. Directly transmitted parasites can be used to gather information on the temporal and spatial characteristics of host species. For example, fast-evolving viruses have been used to reveal contemporary population structure in host species that were not observable using host genetic data (e.g., Biek et al. 2006). If such fast-evolving viruses (e.g., lentiviruses) are present in polar bears, they may prove useful in revealing near real-time changes to circumpolar population structure in response to habitat change. This work will proceed in 2 steps:

(i) Use high throughput genetic sequencing to identify all viruses (including endogenous/non-pathogenic) present in polar bears from a circumpolar sample.
(ii) Compare contemporary (viral) and historic (host) circumpolar population connectivity using viral and host (e.g., SNP or microsatellites) genetic markers.

2. **Climate-induced trophic mismatches**. Climate change, phenological shifts, and the potential for trophic mismatches: implications for polar bears. A well-established consequence of global climate change has been shifts in the phenology of numerous plants and animals (Parmesan and Yohe 2003). When phenological shifts occur to one or more species occupying different trophic levels in the same ecosystem, mismatches in trophic interactions can occur (Post et al. 2008, Both et al. 2009). For polar bears, the increasing duration of the annual ice free period over the continental shelf reduces the ability of bears to prey on ringed seal pups. However, while this climate-based shift deprives bears of access to seals at a particularly critical time, it may increase the temporal availability of other potential prey items such as snow geese (Rockwell et al. 2010). The ameliorative effects, if any, of such trophic matching in alternate prey are unknown and warrant investigation if the potential for resiliency in polar bear foraging behavior is to be fully understood. This work will:

(i) Determine the potential for phenologically-driven matches (e.g., sensu Rockwell et al. 2010) or mismatches to occur between bears and primary and alternate prey.
(ii) Characterize the current spatial extent of phenologically-driven overlap and predict future spatial extents as a function of climate projections.
(iii) Determine potential changes in the degree of sympatry between grizzly and polar bears and implications for competition and hybridization. Recent assessments of the effects of climate change on wildlife have emphasized the need to consider interactive and trophic level effects rather than species-specific projections (Van der Putten et al. 2010). Interactions between species, including predator-prey or competitive interactions, may be altered in ways that will contribute to species-specific responses. Polar bears on the North Slope of Alaska have been spending an increased amount of time on land during the annual sea ice minimum (USGS, unpublished data) and occupy habitats where they are sympatric with grizzly bears. Both species are known to feed simultaneously at subsistence-harvested bowhead whale carcasses in North Slope communities such as Barrow and Kaktovik (USGS, FWS unpubl. data). While much emphasis has been placed on understanding how polar bears are responding to sea ice loss, little is known about the response of the most northern populations of grizzly bears to climate change. Potential changes in diet and range patterns in areas where they are sympatric with polar bears could have consequences for competition and hybridization.

3. **The role of gene expression in fasting ecology**. Use whole transcriptomics to determine if gene expression influences fasting ecology. This work will use samples collected from an icebreaker and on shore in the summer/fall of 2009 to look for differences in the expression of genes associated with fasting. Results of this work could be used to potentially link behavioral

decisions (e.g., go on shore or stay on ice) to the expression of genes.

4. **Assessing immunologic plasticity**. The major histocompatibility complex (MHC) is a multi-gene family that plays a vital role initiation of the immune response. MHC is one of the most polymorphic complexes of the vertebrate genome, with the majority of the polymorphism confined to the region that activates the necessary immune response (Iwasaki et al. 2010). Because of this, MHC presents a unique system to explore links between genetic diversity and pathogens. This work will use samples collected from multiple ecoregions and will add an additional dimension to our understanding of polar bear genetics by allowing us to investigate the links between disease, immune response, and the ability of bears to respond to novel pathogens.
5. **Heredity and fasting ecology**. Is there a genetic basis for ecoregional differences in feeding ecology? This research will investigate differences in the expression of genes (ND5, ND6) believed to be responsible for physiological processes (i.e., metabolism, fat deposition) modulating differences in feeding behavior across ecoregions. Samples from a few individuals representing each ecoregion (if possible) will be used for analyses.

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